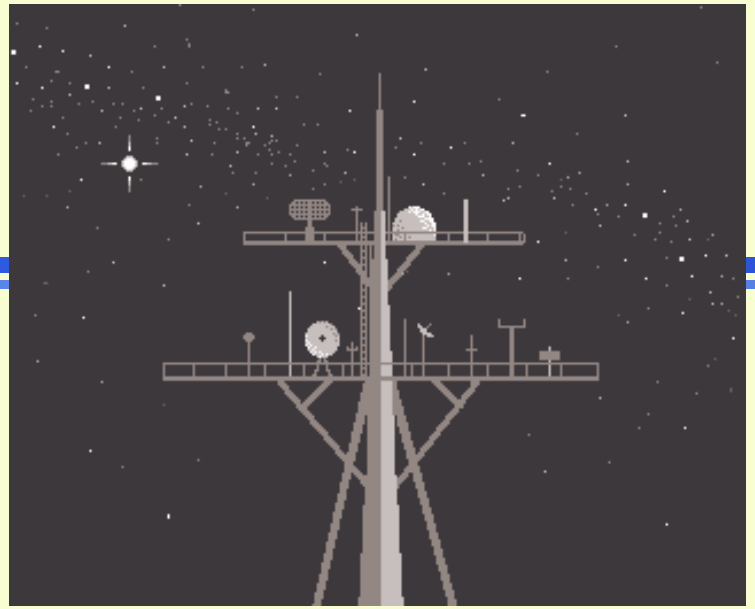


Automated Celestial Systems for Attitude & Position Determination

Sixth DoD Astrometry Forum
U.S. Naval Observatory, 5-6 Dec 2000

George Kaplan
Astronomical Applications Department
Astrometry Department
U.S. Naval Observatory

Isn't GPS Enough?

- Much work now ongoing in DoD to mitigate effects of GPS denial (primarily by jamming)
  - GPS enhancements (AJ, etc.)
  - Complimentary technology
  - Independent technology (alternatives)
- Navy policy requires each vehicle to have two *independent* means of navigation
  - recently reiterated in policy letter

What About INS as a GPS Alternative?

- Inertial navigation systems (INS) are now common on aircraft and ships, both military and commercial
- A form of precise, automated dead reckoning
- Accuracy (position drift) varies widely
- Must be periodically aligned with an external reference system:

GPS **LORAN** **Celestial**

Advantages of Celestial Nav

- Absolute – self-calibrating
- World-wide
- Passive, self-contained
- Nav aids (stars) need no maintenance
- Widespread use and experience

Automating the Celestial Observations

Compared to manual methods, automated systems can provide

- Better accuracy
- Higher data rate
- Determination of platform attitude
- Direct input into INS

Celestial Attitude and Position Determination — Principles

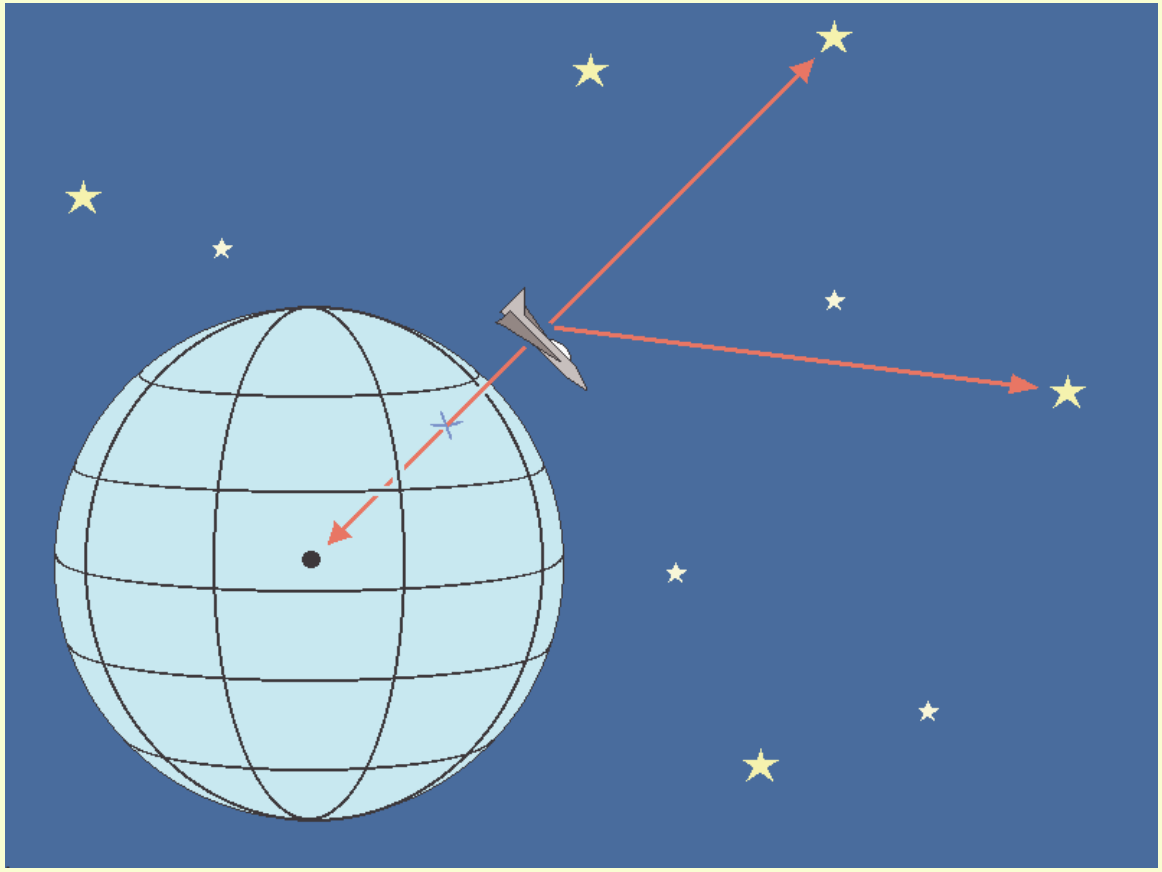
2 or more stars ⇒ 3-axis attitude in inertial space

+ vertical ⇒ attitude wrt horizon

+ time ⇒ latitude and longitude

...*assuming*

star catalog data + formulas for Earth orientation as a function of time



Automated Star Trackers

Used in

- Missile guidance
  - Snark, Polaris, Poseidon, Trident, MX
- Satellite attitude determination
  - XTE, SWAS, STEX, DS-1, WIRE, etc.
- Aircraft navigation
  - SR-71, RC-135, B-2
- Space Shuttle guidance
- Planetary exploration spacecraft

Star Tracker Technology

- Old Technology
  - Gimbaled
  - Single-star observations
  - Photomultiplier tube or similar detectors
  - Programmed observations based on EP & attitude
- New Technology
  - Strapdown
  - Multiple-star observations
  - CCD detectors
  - Automatic star pattern recognition

Star Tracker Technology (cont.)

New vs. old technologies

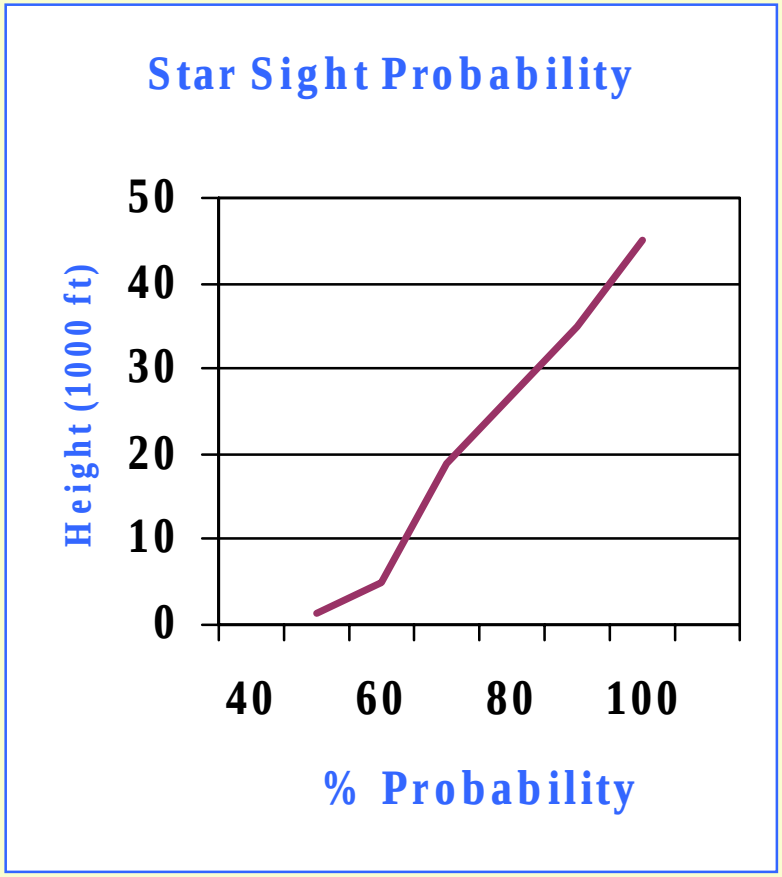
- ~1/3 weight, size, and power
- 3 × MTBF
- Higher data rates

…but, newest technologies mostly confined to space applications so far

Star Tracker Technology (cont.)

Observing in the far red / near IR

- Can observe in daytime — sky dark
- atmosphere more transparent
- ~3 times more bright stars
- CCD quantum efficiency max in red



Star Tracker Examples

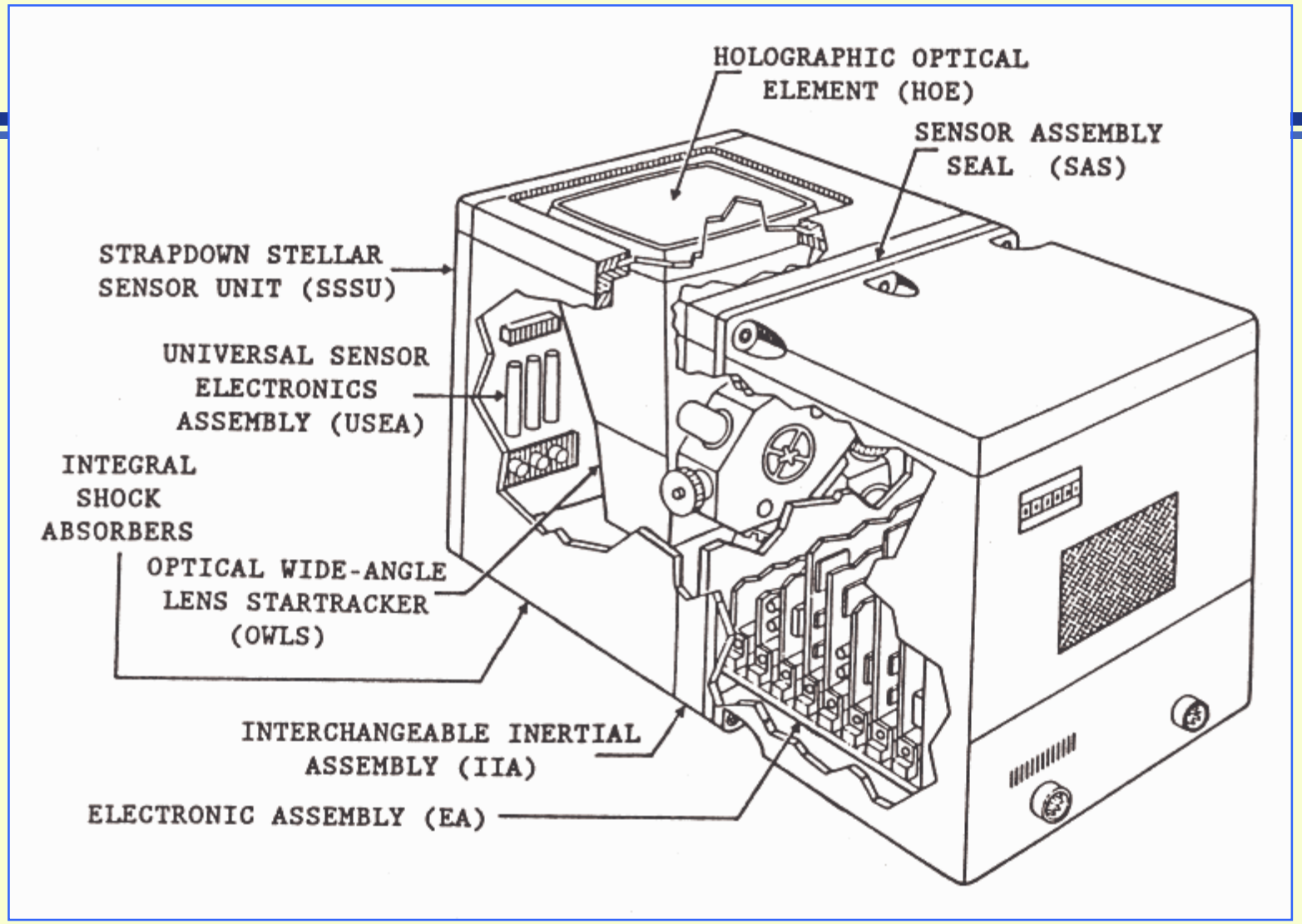
Example 1: B2

- Legacy system from Snark, SR-71
- 150-lb unit in left wing, 10-inch window
- View up to 45º off vertical: out of 52 star catalog, 4-6 stars visible at any given time
- Cassegrain telescope on gimbaled platform
  - 2-inch aperture, 40 arcsec FOV, PMT detector
- Programmed sequence of observations, several per minute
- Azimuth and elevation data back to INS

Star Tracker Examples (cont.)

Example 2: Northrop OWLS

- Strapdown system (non-gimbaled)
- CCD detector, R band (λ 0.6-0.8 μm)
- Three simultaneous 3° fields of view
  - holographic lens
- Stars to magnitude 5 in daylight at sea level
- 1 arcsecond (5 μrad) precision
- 2-axis attitude data back to INS

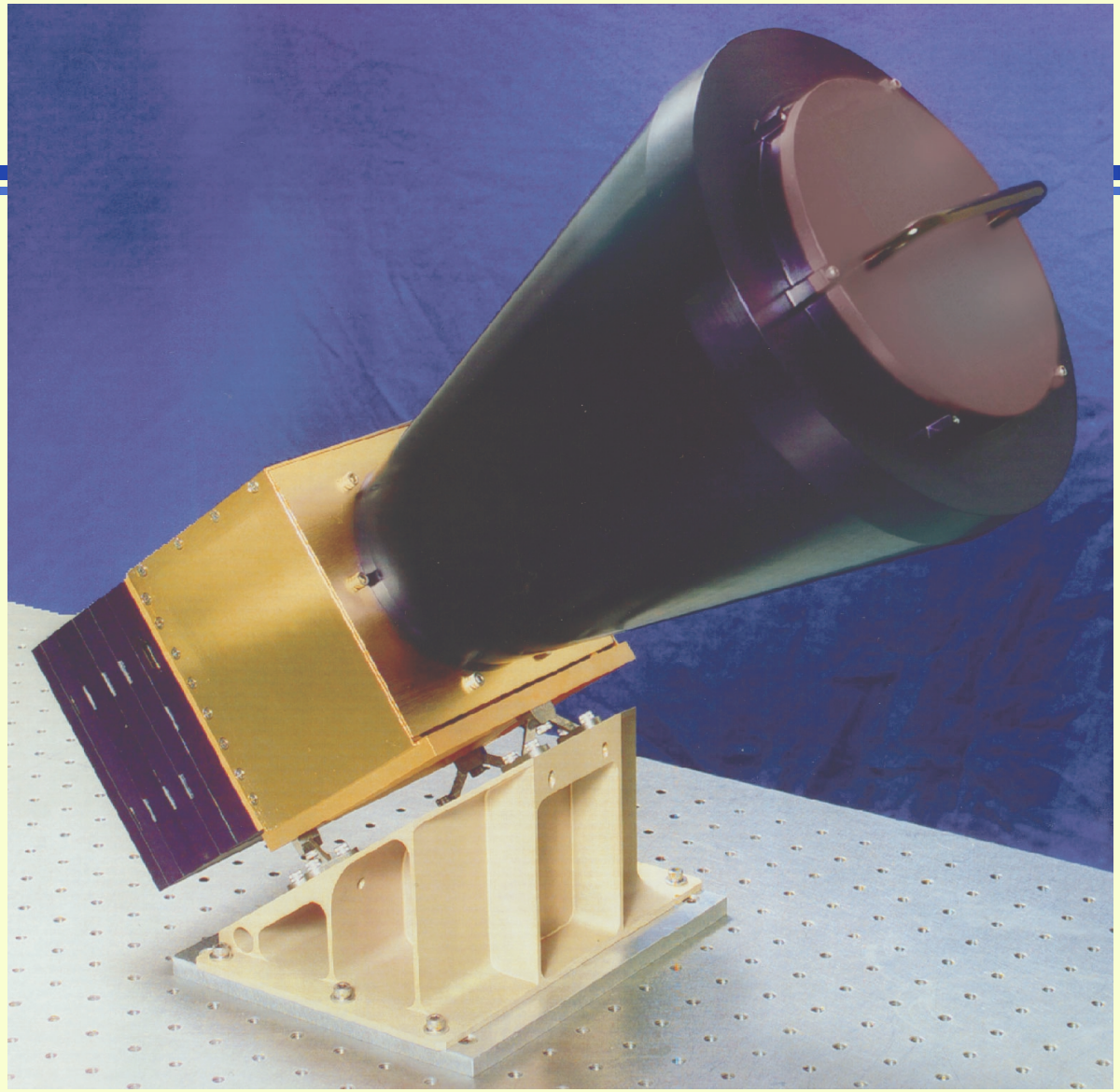

HOLOGRAPHIC OPTICAL ELEMENT (HOE)
SENSOR ASSEMBLY SEAL (SAS)
STRAPDOWN STELLAR SENSOR UNIT (SSSU)
UNIVERSAL SENSOR ELECTRONICS ASSEMBLY (USEA)
INTEGRAL SHOCK ABSORBERS
OPTICAL WIDE-ANGLE LENS STARTRACKER (OWLS)
INTERCHANGEABLE INERTIAL ASSEMBLY (IIA)
ELECTRONIC ASSEMBLY (EA)

Star Tracker Examples (cont.)

Example 3: Lockheed Martin AST-201

- Space qualified
- CCD detector, visual band
- 8.8° field of view, multiple stars
- Stars to magnitude 7, depending on rotation
- 0.7 to 2 arcsecond (3-10 μrad) precision
- Star photons in $\rightarrow$ orientation angles out

  self-contained star catalog, recognition software



Determination of the Vertical

- An easy problem from stationary locations
  - can use precision tiltmeters
- A hard problem from moving vehicles!
  - Motion-related accelerations not separable from gravitational acceleration
  - Generally, must use INS vertical (from NAVSSI?)
  - Other possibilities:
    - horizon sensor
    - atmospheric refraction
    - observe artificial satellites against star background

Conclusions

- Existing DoD astro-inertial systems demonstrate feasibility of accurate autonomous navigation without GPS
- New technology star trackers show promise of wider application possibilities for surface/air navigation at lower cost
- Still TBD: detailed price and performance expectations for new systems